Neutrinos and Dark Matter

Highlights from ICHEP 08

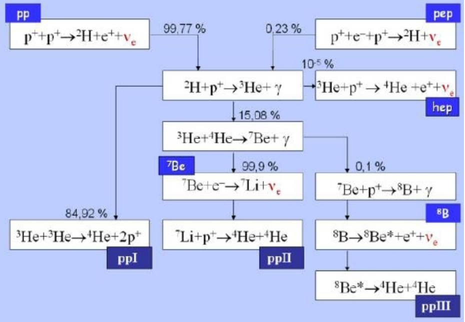
Mary Bishai

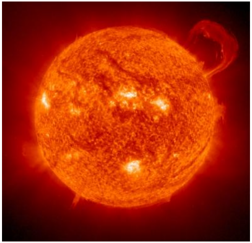
September 18, 2008

Outline

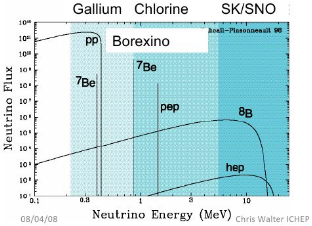
Solar Neutrinos

The pp chain reaction dominates neutrino and energy production in the sun:





The expected neutrino spectrum from the pp chain reaction $\longrightarrow$:



SNO phase III

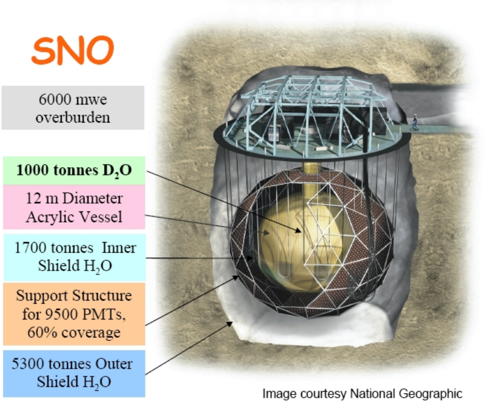
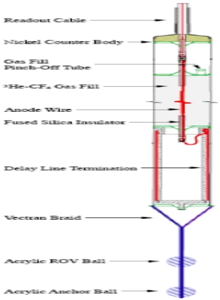


Image courtesy National Geographic



Add ^{3}He proportional counters ("NCDs")

3 reactions:

$\nu_x + e^- \rightarrow \nu_x + e^-$ ES

$\nu_e + d \rightarrow p + p + e^-$ CC

$\nu_x + d \rightarrow p + n + \nu_x$ NC

3 neutron detection methods:

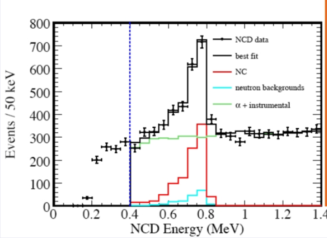
$n + d \rightarrow t + \gamma + 6.25$ MeV Phase I

$n + {}^{35}\mathrm{Cl} \rightarrow {}^{36}\mathrm{Cl} + \gamma + 8.6$ MeV II

$n + {}^{3}\mathrm{He} \rightarrow p + t + 0.76$ MeV III

SNO phase III results

SNO NCD NC Signal:

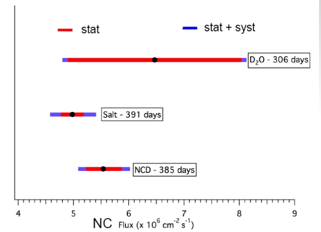


NC Signal:
983 ± 77

Neutron background:
185 ± 25

Alphas and Instrumentals:
6126 ± 250
(0.4 to 1.4 MeV)

SNO NC Phase III results:

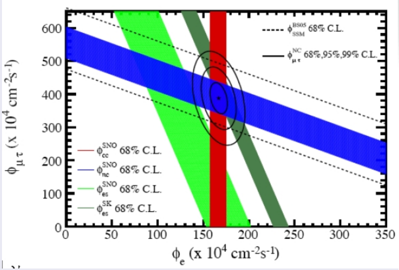


$$\Phi_{\text{total}} = 554(48) \times 10^4 \text{cm}^{-2}\text{s}^{-}1$$

$$\Phi_{\text{SSM}} = 569(1 \pm 0.16) \times 10^4 \text{cm}^{-2}\text{s}^{-}1$$

BSB05-OP: Bachall, Serenelli, Basu Ap. J. 621, L85, 2005

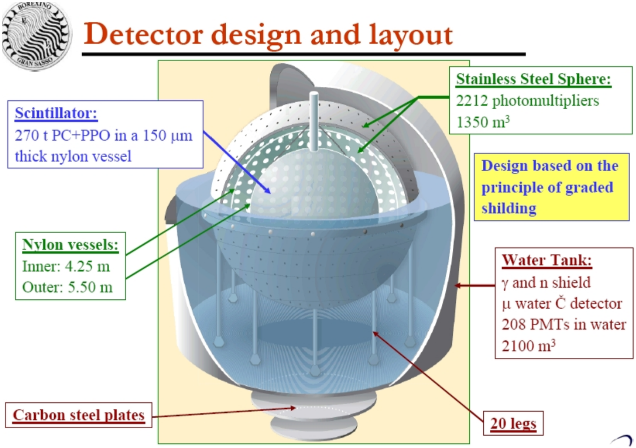
SNO NCD and SuperK:



Borexino

GOAL: Direct determination of the low energy neutrino fluxes: ^{7}Be (monoenergetic) , CNO ($<$ **1%** in our sun), pep, pp

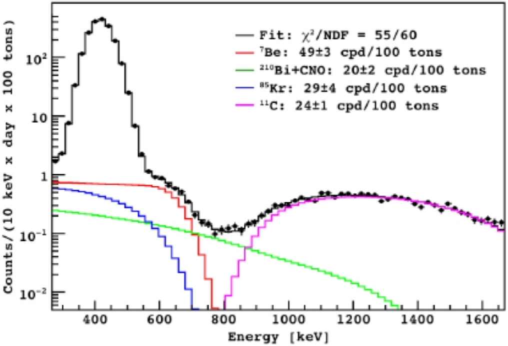
TECHNIQUE: $\nu_x + e \rightarrow \nu_x + e$ elastic scattering in high radio-purity scintillator.



Borexino Results

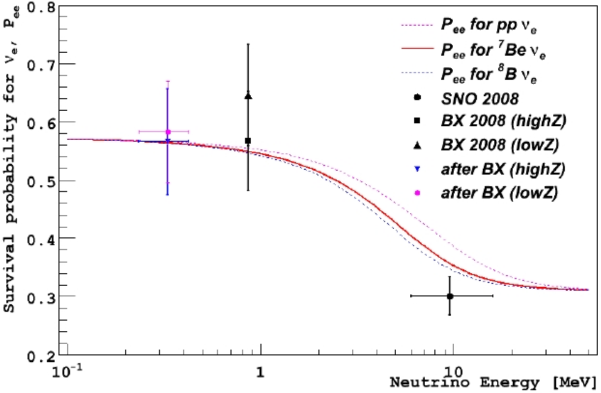
Observe $\mathbf{49 \pm 3_{stat} \pm 4syst}$ cpd/100tons of 862 KeV ^{7}Be ν_e.

No osc expect: **75 ± 5**
MSW LMA expect: **48 ± 4**
$\mathbf{\Phi(^7Be) = (5.12 \pm 0.51) \times 10^9 cm^{-2} s^{-1}}$



SNO + Borexino results 2008

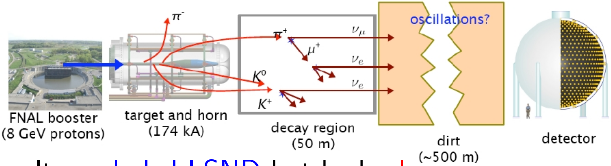
Compared to MSW LMA predictions for $\mathbf{P(\nu_e \rightarrow \nu_e)}$:



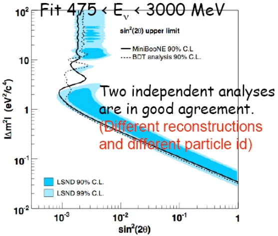
after BX: Ga/Cl data after Borexino

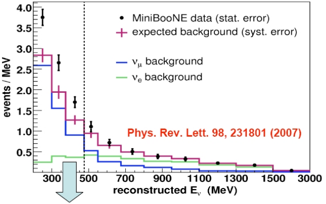
Accelerator neutrinos: MiniBoone

GOAL: Search for short baseline oscillations of $\nu_\mu \longrightarrow \nu_e$
TECHNIQUE:Detects Cerenkov light from QECC interactions of a 0.2-3.0 GeV $\nu_{\mu,e}$ from an accelerator beam in a spherical tank containing 800t mineral oil.



2007 results excluded LSND but had a low energy excess:



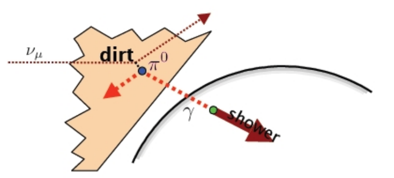


What is the nature of the excess?

MiniBoone - latest results

Exclude dirt events using new cut

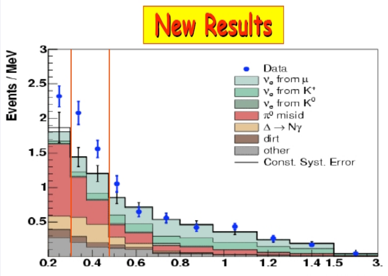
Measure "distance to wall backword" as a function of $\mathbf{E_{vis}}$ and exclude ν_e candidates with short distances. Significant effect below 475MeV. No effect $>$ **475** MeV



Improved modeling of photonuclear absorption

NC $\pi^0 \rightarrow \gamma\gamma$
$\gamma + \mathbf{N} \rightarrow \mathbf{\Delta} \rightarrow \pi + \mathbf{N}$ Adding effect into MC increases π^0 background estimate by 20%

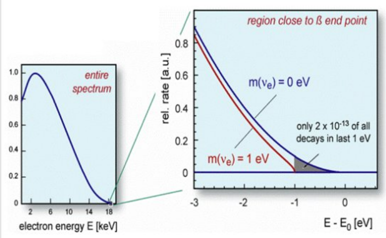
Excess is still $\mathbf{3.4\sigma}$ in 300-475 MeV:

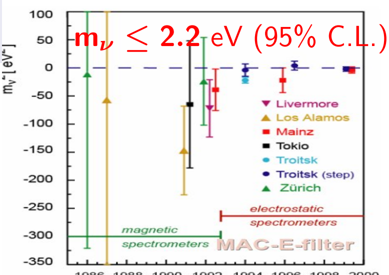


Measuring the absolute mass

Tritium end-point decays

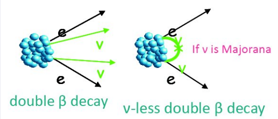
$$^3\mathrm{H} \rightarrow ^3\mathrm{He} + \mathrm{e}^- + \bar{\nu}_e$$

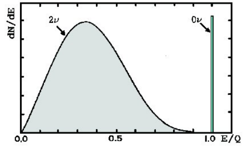


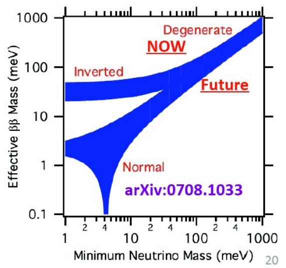


$m_\nu \leq 2.2$ eV (95% C.L.)

Double-β decays

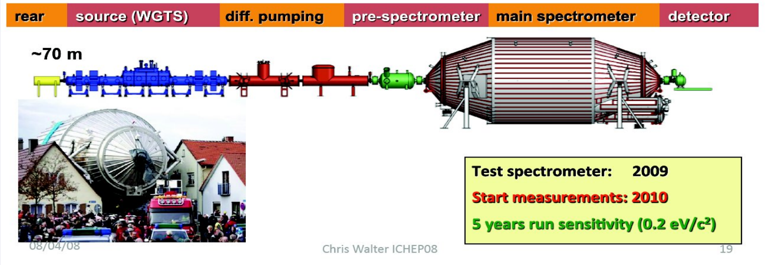






Absolute mass measurements: the near future

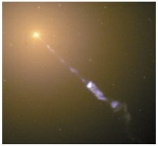
Tritium end point : KATRIN



$0\nu\beta\beta$ decay

- GERDA (CNGS): Uses $^{7}\mathbf{6}$ Ge, $\mathbf{Q_{\beta\beta} = 2.039}$ MeV. Ge diodes with LAr and water shields. Phase II sensitivity: $\mathbf{T_{1/2} > 1.5 \times 10^{26} y, < m_{\beta\beta} > \ < 0.2 eV}$
- EXO (WIPP): LXe 80% enriched ^{136}Xe. 200 kg prototype run for 2 yrs: $\mathbf{T_{1/2} > 6.5 \times 10^{26} y, < m_{\beta\beta} > \ < 0.13 - 0.19 eV}$

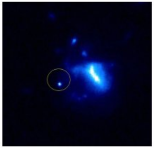
Neutrino astronomy



AGN M87 with Jets from HST

The (Almost) Mundane:

- Neutrino sources may be the same as sources of UHECRs:
  - -AGNs
  - -GRBs
- Covered by the Waxman-Bahcall bound
- Generally assume $L_\gamma \sim L_p \sim L_\nu$

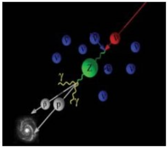


GRB 050709 from HST

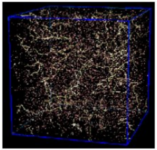
A Little more Exotic:

New mechanisms allow the WB bound to be exceeded

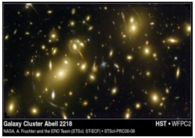
Z-bursts



Topological Defects

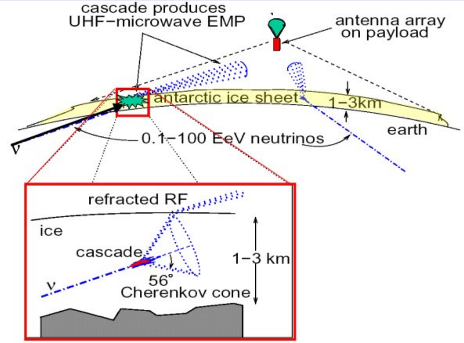


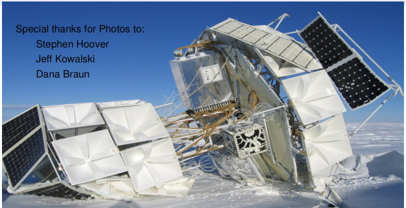
Massive Dark Matter Decays



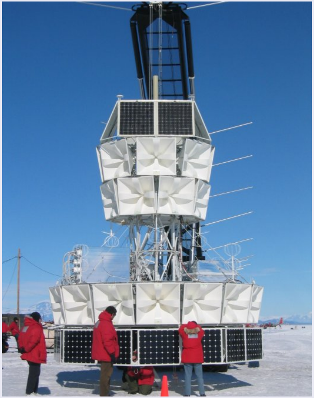
UHE neutrinos using radio Cherenkov

Detection Technique: Askaryan effect

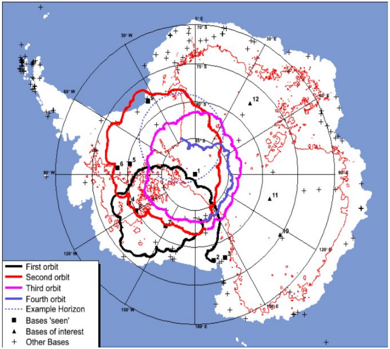


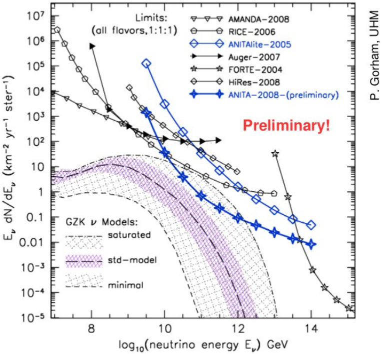


ANITA ballon expt



ANITA Results - Preliminary





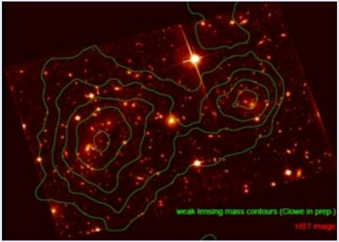
- ANITA '06-'07 flight: No neutrinos identified but work in progress.
- ANITA '08-'09 flight: Improved trigger and hardware - lower energy threshold = $\times \mathbf{3}$ in event rate. Improved trajectory, and live time $\Rightarrow$ possible gain in event rate of ~ 5

Dark Matter-Reprise

- Gravitational lensing studies of the Bullet cluster of colliding galaxies provided the first direct, model independent proof of dark matter:

Bullet cluster: inferred DM (blue), hot gas(red)

Matter density contours



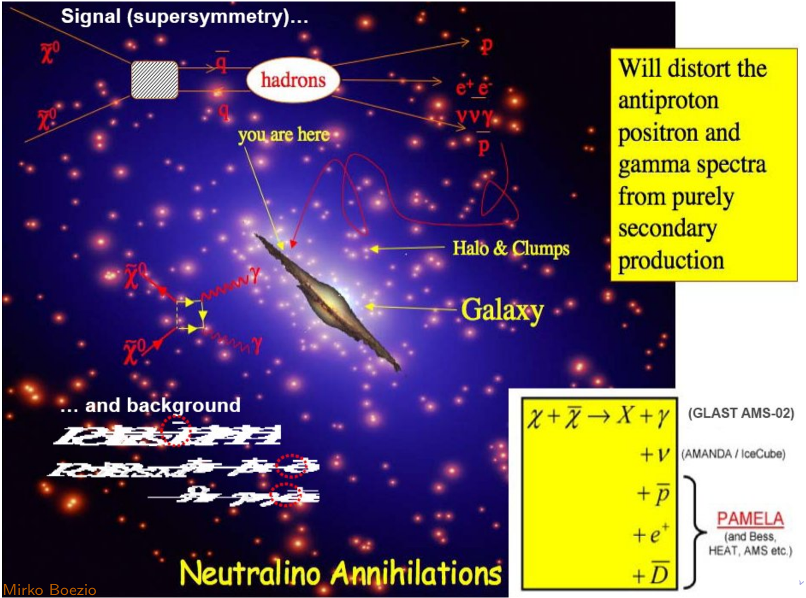
- Bullet cluster excludes some models of MOND.
- 22% of matter in the Universe is dark, non baryonic, and requires physics beyond the SM

Dark matter searches

The type of search depends on the type of DM assumed

- Hot DM (relativistic): most probably neutrinos $\Rightarrow < 0.02$ of total. Moves too fast - cant clump to form galaxies.
- Warm DM (semi-relativistic): Sterile neutrino, gravitino, non-thermal neutralino.
- Cold DM (non-relativistic): WIMPs (LSP), axion, WIMPZILLA, Q-balls,

Indirect searches for WIMPS

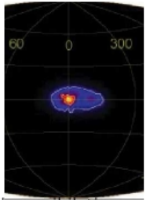


Indirect WIMP search summary - tantalizing hints

Graciela Gelmini-UCLA

Indirect DM Searches: round of WIMP signals?

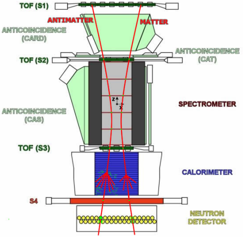
- CANGAROO, VERITAS, HESS 0.2-10 TeV γ's from the GC
  Found by HESS in 2006 not due to DM (DM $<$ 10%)(PRL97, 221102, 2006)
  Thus window for GLAST observation from GC reduced! Zaharijas, Hooper 2006
- EGRET excess in 1-10 GeVγ's from the GC Can be due to 80 GeV WIMP annihilation (GLAST will tell) Cesarini et al. , 2003
- INTEGRAL 511 keV line from the GC (30 y old)
  Jan 2008: region not spherical but deformed towards LMXB!
  SO NO DM AFTER ALL? Tuned DM particles were proposed:
  -MeV mass LDM (Light DM) annihilation-Boehm et al 04, Beacom et al 04
  -500 GeV mass XDM (eXciting DM)- D. Finkbeiner 2007

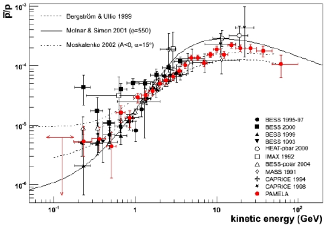


- "WMAP haze" at the GC Finkbeiner et al. 2004
  Most WIMP models explain it as synchrotron from e e^+ produced in annihilations
  Hooper Zaharijas Finkbeiner and Dobler; astro-ph/0709.3114; Cholis, Goodenough and Weiner; arXiv:0802.2922
- HEAT excess in $\bar{e}$ from the halo, 1 to 50 GeV (confirmed by PAMELA?)

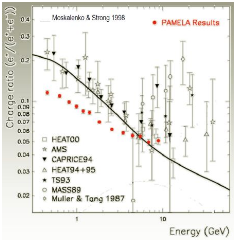
PAMELA e^+ from halo excess

PAMELA(Payload for Antimatter Exploration and Light nuclei Astrophysics) a satellite experiment : first light July 11$^{\text{th}}$, 2006

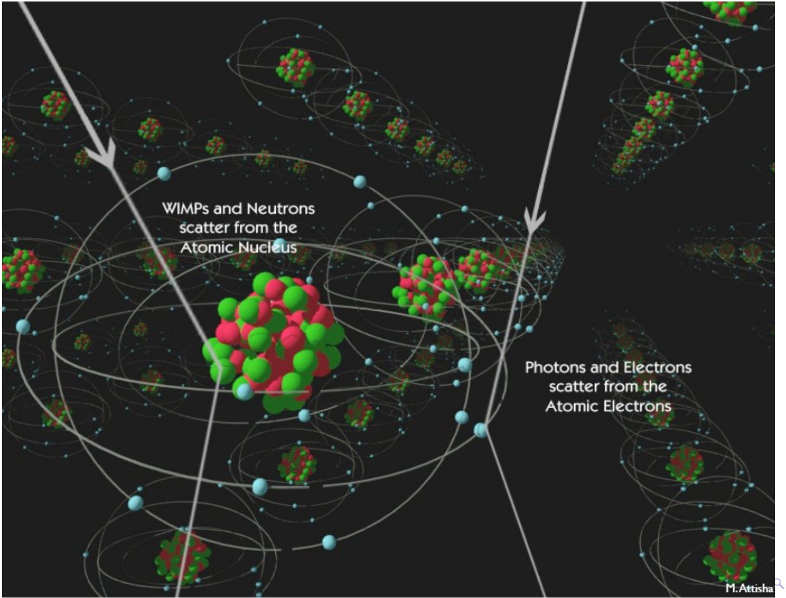




- $\bar{\mathbf{p}}/\mathbf{p}$ ratio consistent with expectation
- $\mathbf{e}^+/(\mathbf{e}^+ + \mathbf{e}^-)$ ratio shown up to 9 GeV, can measure up to 270 GeV
- Low energy data lower than theoretical prediction (black line) due to solar modulation effects < 10 GeV.



WIMP direct searches



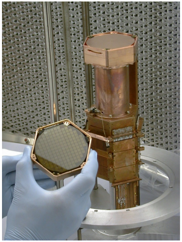
Direct search experiments

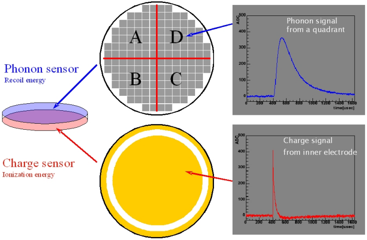
- Solid state detectors
  - Ionization (Ge, Si, CdTe):HDMS GENIUS, TEXONO,CoGENT
  - Scintillation (NaI,CSI) : DAMA
  - Phonons (Ge, Si, Al_2O_3, TeO_2): CRESST-I,CUORE,Cuoricino
  - Hybrids: CDMS (ionization+phonons), CREST II (scintillation +phonons)
- Bubble chambers
  - PICASSO: bubbles of C_4F_1O
  - COUPP: superheated bubble chamber
- Noble gases

Gas	Single Phase	Double phase
Xe	ZEPLIN,XMASS	ZEPLIN, XENON, XMASS
Ar	DEAP,CLEAN	WARP, ArDM
Ne	CLEAN	SIGN

CDMSII: latest results

Uses both Si and Ge targets, detects both phonons+ionization signal.

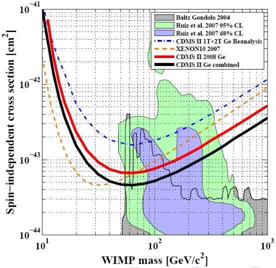




CDMSII five tower run in Soudan. 4.75kg Ge + 1.1 kg Si.

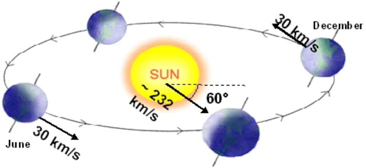
Exposure: 397.8 total kg-days (121.3 effective)

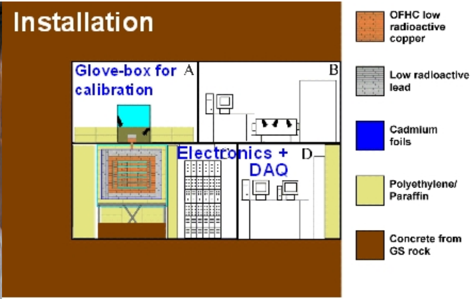
Null observation = zero background!



The DAMA experiment

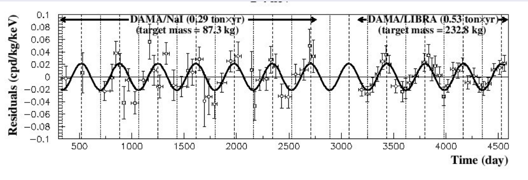
DAMA/NaI (100kg) and DAMA/LIBRA (250kg) use scintillation in NaI(TI) crystals. Search for an annual modulation Model Independent:





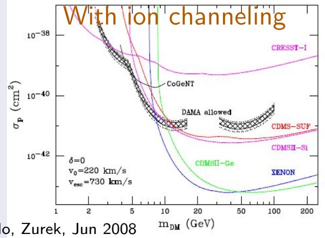
DAMA results

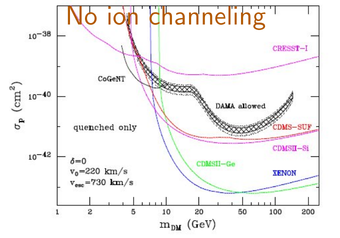
Annual modulation observed in DAMA/NaI & LIBRA



Are these results compatible with new CDMS/XENON?

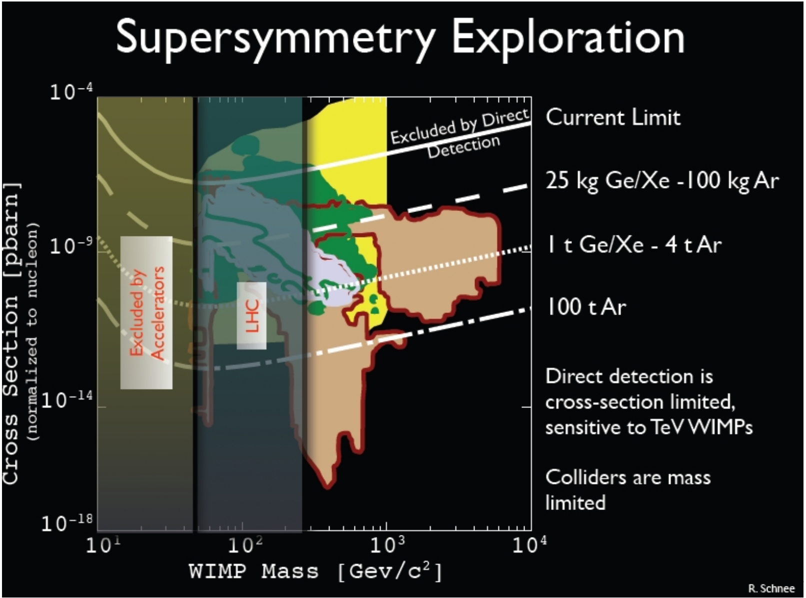
Ion channeling effects: ions moving along crystal axes penetrate longer and loose more energy. Effects need to be included.





Petriello, Zurek, Jun 2008

Direct searches - the future with Noble gasses



- The strongest experimental evidence we have for physics beyond the SM are from the observation of neutrino oscillations and DM.
- The total solar neutrino flux has been measured to better than 10% $\Rightarrow$ we understand our sun. Nice to know we understand our corner of the galaxy!
- This is the dawning of the age of neutrino astronomy. ν telescopes are being built and taking data. Antartica = biggest terrestrial telescope (assuming the ice doesnt melt).

- Limits on ν masses from terrestrial experiments indicate ν (candidate for hot DM) is a tiny fraction of DM which is 22% of the Universe.
- Sterile neutrinos are candidates for warm DM, but currently no evidence for them in accelerator based neutrino searches since MiniBoone excluded the LSND results. BUT a 3.4 σ discrepency in the MiniBoone low energy region persists - who ordered that?.
- WIMPs remain the best candidate for DM. If there is SUSY then $\bar{\chi}^0$ is a WIMP candidate.
- We have some tantalizing hints from indirect WIMP seaches for $\chi^0 + \bar{\chi}^0 \rightarrow \mathbf{X} + \gamma/\mathbf{e}^+$
- WIMP model independent observation from DAMA is not consistent with other direct searches, but comparison is not straightforward.